Forward Looking Acoustic Sensors for Divers and Small Underwater Vehicles

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LONG-TERM GOALS

The goal of this task is to identify and develop acoustic sensor technology that can be diver-portable or integrated onto the front of an underwater vehicle. The sensor will be capable of detecting and localizing fully buried mines, and detecting, classifying, and localizing volume and partially buried mines. This task is a joint effort with work being performed by the "Diver-Portable Multi-Sensor Buried Mine-Hunter" which is being conducted under the 6.2 Naval Special Warfare (NSW) Technology Program. The overall goal of this joint effort is to develop a complete system that will be no larger than 10-inches in diameter with a 20-inch length, will be neutrally buoyant in water, and will weigh less than 35 pounds in air.

OBJECTIVES

This task seeks to identify and develop technology that will detect and localize fully buried mines as well as to detect, classify, and localize volume and partially buried mines.

APPROACH

The approach of this task is to leverage as much as possible from the work being performed under the 6.2 NSW Technology Program such that a buried mine sensor system that can be diver-portable or attached to the front of an underwater vehicle is developed. The overall approach to this development consists of five distinct efforts; the 6.2 NSW Technology Program and 6.3 Diver Core Program portions of these efforts are identified. In the first effort (6.2 program), an assessment of individual sensor technologies was conducted to determine the most viable concept(s) for the sensor system. From this work, issues associated with candidate sensor concepts were identified and addressed in the second effort (6.2 program). In the third effort, the candidate sensor concept(s) will be designed and algorithms needed to process and display the signals will be developed (6.2 and 6.3 programs). The individual sensor(s) will be tested in the fourth effort (6.2 and 6.3 programs). In the fifth effort, the sensor(s) will be integrated and demonstrated (6.3 program).

The key issues needed in identifying candidate sensor concepts include:

(a) Determination of the effectiveness of a sonar (frequency, aperture size, beam pattern, pulse type, signal processing techniques, etc.) to detect completely buried mines.

(b) Identification and development of the technology that will provide capability in classification.

(c) Integration and packaging of these sensors into a diver-portable unit or a unit that can be attached onto the front of an underwater vehicle.

In regard to issue (a), while there exists sonar performance models such as SEARAY and the shallow water acoustic tool set (SWAT) which predict sonar performance against volume and partially buried mines, there does not exist validated models that accurately predict sonar performance against buried mines. The key modeling issues are to accurately predict the amount of acoustic energy that can propagate into and out of the sediment. Several experiments have measured higher acoustic penetration into sediment at shallow grazing angles than expected.[1-4] Two proposed explanation for this penetration are: (1) the excitation of a biot slow wave in the sediment in which porosity and permeability of the sediment are important factors[5] and (2) scattering of the acoustic beam into the sediment by patches of roughness at the water-sediment interface.[6] In order to properly determine sonar tradeoffs (i.e., frequency, aperture size, beam pattern, etc.), an accurate accounting of penetration to, and backscatter from, a buried target needs to be incorporated into a sonar performance model. Thus, a validated model that predicts sonar performance against buried targets is unresolved.

WORK COMPLETED

Under the 6.2 NSW Technology Program, a concept feasibility study identified that a wide field-of-view (FOV), multiple-beam, dual-frequency (low frequency for buried mine detection and higher frequency for imaging/classification capability) acoustic lens sonar was the best candidate sensor that could be diver-portable or attached to the front of an underwater vehicle.[7] This study also identified the lack of data associated with the material property (attenuation at frequencies less than 100 kHz and speed of sound) in candidate acoustic lens materials. In the second effort performed under the 6.2 NSW Technology Program, an experiment was conducted to obtained measurements of attenuation and speed of sound for different candidate elastomeric materials (various compositions of neoprene, EPDM, and nitrile as well as hypalon and silicone). Results of this effort were used to determine a candidate lens design for the dual frequency system.

In FY98, a partially populated, lower frequency portion of the candidate lens systems was designed, fabricated, and tested under the 6.2 NSW Technology Program. The acoustic performance of this design was assessed against buried targets in a measurement conducted in the Very Shallow Water (VSW) region near the Army Corps of Engineers Field Research Facility in Duck, NC. The measurements employed three lower frequency subsystems that were identical in design, but with different diameters (aperture diameters were 20, 25, and 30 cm); these systems were attached to a stationary sonar tower complete with horizontal pan and vertical tilt motors. Calibrated retro-reflectors were used for the buried targets, and a buried hydrophone array was employed to determine the coherence of the transmitted signal in the sediment. The goal of this measurement was to establish an optimum combination of frequency and aperture size for buried target detection in a VSW environment.

In FY99, the data collected in the FY98 testing were processed and analyzed (6.2 program). The processed data included: calculating signal-to-background ratios of the backscattered signals from the buried retro-reflectors; and determining the coherence of the signal transmitted into the sediment by using a magnitude square coherence technique. Results indicated that adequate signal-to-background ratio was maintained for target detection for each of the three diameter subsystems; the signal-to-background increased with increasing diameter.[8] In addition, the coherence of the transmitted pulse was found to decrease with depth in the sediment and with increasing frequency.[8] From this analysis, a sonar aperture size of 25 cm was selected, and the dual frequency lens system was designed (6.3 program) in a modular form. Here the aperture of the lower frequency subsystem is truncated such that the higher frequency subsystem is located at this truncated position. The aperture size was selected based on the combination of size constraints and results of the FY98 testing. Partially populated lower and high frequency subsystems were fabricated for testing (6.2 program). Two models were developed. One model created computer-generated images to provide guidance in determining sonar parameters required for classification-type images (6.2 program) while the other assessed impact of beam-to-beam interface for a fully developed system (6.3 program).[9] An effort was also initiated to identify processing requirements needed to control the dual frequency acoustic lens system.

Four efforts were conducted in FY 2000. First, issues dealing with a fully populated diver-portable and vehicle mounted forward looking systems were identified. Second, hardware concepts for a final system were tested. Third, candidate off-the-shelf processing hardware was identified. Fourth, using the higher frequency lens subsystem's sonar parameters as inputs, the SWAT code was used to predict the probability of classification. In an additional effort performed under the 6.2 NSW Technology Program, partially populated lower and higher lens frequency subsystems were assessed during the ONR sponsored Department Research Initiative (DRI) experiment "High-Frequency Sound Interaction in Ocean Sediments" and during tests conducted at a sandy bottom site in St. Andrews Bay near the CSS Ammo Pier. From the FY 2000 measurements, the sonar parameters for buried target detection will be finalized and the appropriate sonar parameters needed to obtain classification-type images will be determined. A fully populated dual frequency system will be fabricated and tested.

RESULTS

System Issues. An effort was initiated that identified issues dealing with a fully populated system that could be either diver-portable or mounted onto the front of a vehicle. The identified issues are:

- Diver ergonomics (size, center of mass and buoyancy, display visibility, control switches, etc.)
- Power requirements and recharge capability of energy source
- Interference and cross-talk between channel-to-channel
- Source level/receive sensitivity/noise floor requirements for imaging ranges approaching 20 m
- Data recording capability

- Packaging of electronics in limited space and dissipation of heat generated by electronics
- System ruggedness (bonding to lens material, higher frequency transducer construction, etc.)

These identified issues will be addressed in FY 2001.

Testing of Hardware Concepts for Final System. In developing hardware concepts for the final system's design, a functional block diagram was generated which allowed for the identification of critical requirements. These requirements were deemed crucial in developing an optimal architecture that would maximize the performance-to-weight/volume ratio. Some of these blocks were fabricated, implemented, and tested in the partially populated subsystems used during the sensor assessment efforts (DRI measurement and CSS ammo pier tests conducted under the 6.2 program). This permitted test and evaluation of techniques and components used in both lower and higher frequency array, preamplifier, multiplexor, and power amplifier subassemblies. Fabrication tasks in the final, complete dual frequency system will be greatly enhanced by information gathered, techniques developed, and components verified during the sensor assessment efforts.

Processing Requirements. An effort was initiated to identify the processing requirements needed to control the dual frequency acoustic lens system. Tradeoffs considered in this effort included: size, power, memory, temperature, and the short developmental time frame. Based on the availability of pre-existing development platforms, Intel processors appear to be the most viable candidates. The Mobile Pentium III 400MHz Plug-N-Run System-On-A-Module with three PCI expansion slots was identified as an off-the-shelf candidate processor system. Innovation Integration ChicoPlus baseboard with two A4D1 modules would be placed in the slots. This system will requires 5 Watts of power and will be 8-inches by 4.5-inches by 4.5-inches in size.

SWAT Predictions. The SWAT code was used to obtain predictions of the probabilities of detection (P_D) and classification (P_C) for the higher frequency lens subsystem. P_C is calculated using the expression, $P_C = P_H + P_L - P_H \times P_L$. Here P_H and P_L is the probability of classification due to highlights and shadows, respectively. Inputs to the code are listed in Table 1 and include sonar source level, frequency, and beam widths as well as water depth, sonar depth, target depth, and target strength. Figure 1 illustrates SWAT predictions of P_D (red line) and P_C (blue line) versus range. For the ranges considered, P_D is greater than 0.95. P_C is over 0.95 at 5 m and gradually decreases to about 0.7 at 20 m (anticipated maximum range capability). The SWAT code was also used to predict P_C versus range for several other forward-looking systems. This effort indicated that for the ranges considered, the higher frequency lens subsystem provides higher probability of classification than the other forward looking systems. This is due to a combination of frequency and resolution. For comparable resolution systems, the higher frequency lens subsystem operates at a frequency much less

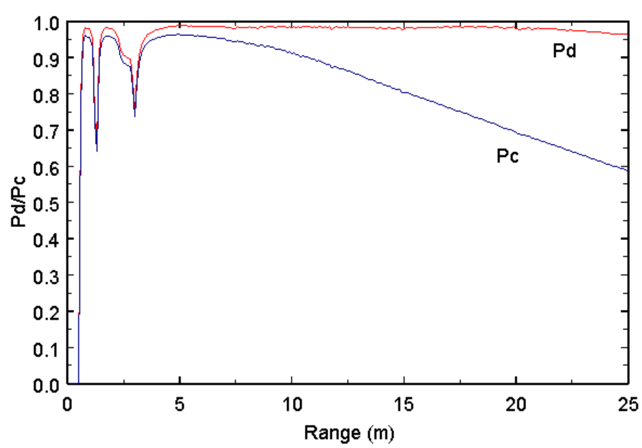

Figure 1. P_D and P_C versus range.

than the other systems, thereby reducing effects dealing with attenuation, while other systems that operate at reduced frequencies have significantly reduced resolution.

Table 1. Inputs used in the SWAT code

Source level = 190 dB	Frequency = 1.2 MHz
Two-way beam widths = 0.27° x 10°	Water depth = 3 m
Sonar depth = 3 m	Sonar tilt angle = 1°
Target depth = 2.99 m	Target strength = - 20 dB

IMPACT/APPLICATIONS

The diver-portable/forward looking sensor technologies developed under this task will be used to replace the Fleet AN/PQS-2A diver-portable sonar and to operate on small autonomous underwater vehicles (AUVs). The expected payoffs for the developed technology include:

- More reliable buried target detection capability than that of present systems.
- Improved classification capability.
- Higher area coverage rates.
- Reduced mission execution times.
- Higher probability of mission success because of fewer missed detection opportunities.

TRANSITIONS

The most likely transition path for the forward looking acoustic sensor as well as the developed detection and classifier technology will be to the Program Management Office- Explosive Ordnance Disposal (PMS-EOD) associated with the VSW Mine Countermeasures (MCM) Detachment or Special Operations Command (SOCOM). Another possible transition path for the developed classifier technology is PMS 407, which sponsors efforts associated with the Fleet's Mine Neutralization System (MNS).

RELATED PROJECTS

This task is leveraging work being conducted under the 6.2 NSW Technology Program entitled, the "Diver-Portable Multi-Sensor Buried Mine-Hunter

An advanced motion compensation for Synthetic Aperture Sonar (SAS) task funded by ONR seeks to increase the area coverage rate of present SAS systems by developing sophisticated motion compensation algorithms.

The Direct Research Initiative (DRI) program "High-Frequency Sound Interaction in Ocean Sediments" is an ONR funded 6.1-type research effort which an objective to provide a physical understanding of the observed penetration into sediment at shallow grazing angles.

An acoustic lens effort, funded by ONR under an EOD program, is using acoustic lens techniques to develop a high resolution, short-range (less than 10 meters) imaging sonar which will operate in the frequency range of 2 to 3 MHz.

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